Infrapopliteal arterial revascularization for critical limb ischemia: Is the peroneal artery at the distal third a suitable outflow vessel?

Enzo Ballotta, MD,[a] Giuseppe Da Giau, MD,[a] Mario Gruppo, MD,[b] Franco Mazzalai, MD,[b] and **Bruno Martella, MD,[b]** *Padova, Italy*

Purpose: **Though the peroneal artery (PA) often remains patent despite disease or occlusion of other infrapopliteal arteries, there is skepticism about using the terminal PA as the outflow tract in distal revascularizations for limb salvage, especially when a patent inframalleolar artery is available. We analyzed our experience of using the distal PA and inframalleolar or pedal branches arteries as outflow tracts in revascularizations for critical limb ischemia.**

Methods: **Over a decade, among 651 infrapopliteal arterial reconstructions performed in 597 patients, the PA was the outflow vessel in 214, its distal third being involved in 69 vein revascularizations (study group). During the same period, 187 vein bypass grafts were performed to 179 inframalleolar and 8 pedal branches arteries (control group). Patency, limb salvage and survival rates were assessed using Kaplan-Meier life-table analysis. Complete follow-up (range, 0.1-10.2 years; mean, 5.8 years) was obtained in 245 (95.7%) patients (66 were in the study group).**

Results: **The distal PA was chosen as the target vessel: (1) because the proximal, mid-PA was occluded or severely diseased and no other adequate inframalleolar or pedal branches arteries were identified preoperatively (n = 30; 43.5%); (2) because an alternative inframalleolar target vessel was present but severely diseased (n = 9; 13%); (3) because of the length limitations of the available vein (n = 12; 17.4%; or (4) because of the presence of invasive infection or necrosis overlying the dorsalis pedis or posterior tibial arteries (n = 18; 26.1%). The study group was significantly younger than the control group (68 ± 7 years vs 70 ± 6 years, $P = .039$), and included significantly more patients with diabetes mellitus (65.2% vs 50.2%, $P = .033$) and insulin dependence (52.2% vs 37.9%, $P = .041$), dialysis-dependent chronic kidney disease (5.8% vs 1.1%, $P = .047$), and history of smoking (75.3% vs 58.2%, $P = .012$). None of the patients died in the perioperative period. Although the overall need for minor amputation was statistically higher in the PA group (78.2% vs 63.1%, $P = .022$), especially as concerns partial calcanectomy (8.7% vs 2.1%, $P = .026$), the proportion of wounds completely healed during the follow-up and the mean time to wound healing were comparable in the two groups. Kaplan-Meier analysis showed comparable long-term patency, limb salvage, and survival rates in the two groups.**

Conclusions: **Revascularization to the distal third of the PA can achieve much the same outcome in terms of patency and limb salvage rates, wound healing rate and timing, as when other inframalleolar or pedal branches are used. The skepticism surrounding use of the terminal PA as an outflow vessel appears to be unwarranted. (J Vasc Surg 2008; 47:952-9.)**

Long-term patency and limb salvage (LS) rates after infrapopliteal arterial revascularization to the peroneal artery (PA) for critical limb ischemia (CLI) are comparable with those achieved using other tibial outflow arteries.[1-10] Using the PA in lower extremity arterial reconstruction has always been a controversial issue, however, especially when a patent inframalleolar artery is available.[11-14] The PA is relatively spared from the terminal stages of atherosclerosis[1,15] and is often the last tibial vessel to become occluded in diabetes or end-stage vascular disease.[1,2] The main prejudice, on the other hand, against its use in distal revascularizations is that perfusion of the foot is indirect, via collaterals from its anterior and posterior branches, despite an extensive collateral arterial bed, so the target vessel may be inadequate for treating a septic or gangrenous foot.[11,13,16,17] Inframalleolar vessels include the posterior tibial (PT) artery, at or below the medial malleolus, the dorsalis pedis (DP) artery, and the pedal branches (PBs) arteries, defined as any tarsal, plantar, or anterior lateral malleolar arteries.[18] Though these vessels are commonly exposed in septic areas, which may increase the incidence of wound complications, inframalleolar reconstructions restore a pulsatile, direct arterial perfusion of the ischemic or septic foot, in close proximity to the ischemic lesion. Proximal and mid-PAs are used as outflow segments, especially when any other inframalleolar artery is suitable, but the terminal PA (within 5 cm of the malleolus) is regarded with skepticism by many authors, who question the efficacy of such revascularizations in LS and consider exposing the artery's distal third demanding.[9,19]

The purpose of this study was to analyze our experience of bypass procedures to the distal third of the PA to see whether such revascularizations could yield comparable or even better results, in terms of patency and LS rates, wound

From the Vascular Surgery Section of the Geriatric Surgery Clinic[a] and the Geriatric Surgery Clinic,[b] Department of Surgical and Gastroenterological Sciences, University of Padua, School of Medicine.

Competition of interest: none.

Reprint requests: Enzo Ballotta, MD, Vascular Surgery Section of the Geriatric Surgery Clinic, Department of Surgical and Gastroenterological Sciences, University of Padua, School of Medicine, 2° Piano Ospedale Giustinianeo, Via N. Giustiniani, 2 Padova, Italy 35128 (e-mail: enzo.ballotta@unipd.it).

0741-5214/$34.00

doi:10.1016/j.jvs.2008.01.002

healing rate, and timing, than the more conventional reconstructions to inframalleolar or PBs arteries in patients with CLI.

METHODS

From January 1995 to October 2005, all consecutive patients requiring an infrapopliteal bypass at our institution for CLI (rest pain and/or ischemic ulceration, or gangrene limited to the heel or forefoot) were prospectively entered in a vascular surgery registry. For this study, the registry was queried to identify patients who underwent autogenous vein bypass to a terminal PA (study group) or to inframalleolar or PBs arteries (control group) as an outflow vessel up until October 2005. Patients with ischemic soft tissue breakdown between the calcaneous and metatarsal heads (plantar region) and those who had bypasses to target arteries proximal to the ankle or using synthetic conduits were ruled out.

Demographic data and preoperative risk factors, including diabetes mellitus, smoking, arterial hypertension, coronary artery (CAD), or chronic kidney diseases (CKD), were recorded for each patient, along with the inflow site. All patients underwent preoperative standard biplanar arteriography or magnetic resonance angiography, and computed tomography angiography, or a combination of these methods, to confirm the clinical and vascular laboratory diagnosis (duplex ultrasonography arterial mapping and ankle-brachial index [ABI] measurement) of CLI and to plan surgery. The preoperative angiographic findings of the runoff vessels were assessed according to the revised ad hoc scoring system proposed by Rutherford et al.[20] Because bypassing to a single tibial artery or the DP are examples of a normally single-vessel runoff, runoff was assessed grading the resistance of the pedal arch. A value of 0 was assigned for a completely patent arch connecting with retrograde flow back into the other pedal artery (eg, lateral plantar or medial tarsal), 1 for patent arch with no retrograde outflow, 2 for a diseased or partially occluded arch, and 3 for little or no arch visualized.[20] Arbitrarily, 1 point was added to this score in bypass grafts to the PA, in recognition of its lack of direct connection with the pedal artery circulation.[20] The preferred conduit was the reversed autogenous great saphenous vein (SV), which was harvested whenever possible on the strength of venous mapping by duplex scan, subject to direct assessment at surgery. When the ipsi- or contralateral great SV was unsuitable or not entirely available, spliced veins (great or small SV and arm vein) were used. Short bypass revascularizations were used when distal superficial femoral, popliteal, or tibial arteries seeming adequate for inflow at preoperative angiographic evaluation were in fact found appropriate by the operating surgeon. None of the patients underwent in situ bypass grafting. No intraoperative contrast or duplex scan arteriography was performed. All foot lesions were treated preoperatively according to a protocol described elsewhere,[21] and local wound care was continued after surgery as necessary. Additional procedures involving the forefoot or heel were recorded. Taking the arterial revascularization time for reference, ulcers, or gangrene were analyzed in terms of the time it took for the wound to close completely by secondary intent or to heal completely after any additional procedure.

Operative technique. All revascularizations were performed by the senior surgeon using regional anesthesia (epidural or spinal) and administering intravenous heparin (5000 IU) before clamping: the heparin was not reversed with protamine. In all but four cases, the distal PA was exposed using a lateral approach requiring segmental fibulectomy. The incision is based laterally over the fibula and, after freeing it of all muscle and fibrous tissue over a stretch of at least 8 cm, the bone is resected (in our experience, the mean length of the remaining distal fibula was 8-10 cm and no ankle instability was observed in our patient group), facilitating access to the PA lying just medial to the resected bone on the flexor hallucis muscle. The medial exposure of the distal PA involves the longitudinal division of the deep fascia and the posterior displacement of the gastrocnemious and soleus muscles. The dissection plane is established behind the PT vessels where the distal PA and its terminal branches are easily identified once the tibial nerve has been retracted anteriorly and the flexor hallucis longus muscle posteriorly. After proximal and distal arterial exposure, the distal anastomosis was performed first. All distal anastomotic sites underwent standard vein patch angioplasty no longer than 3 cm, as described elsewhere.[21,22] The vein for the patch was harvested from any available location, including SV remnants, arm veins harvested under local anesthesia, and occasionally also SV collaterals. The vein conduit was routed through the interosseous membrane when PA was exposed laterally. Heparin infusion was started 6 to 10 hours postoperatively, administering oral warfarin on the first postoperative day, and continuing anticoagulation treatment for the next 6 months; 325 mg aspirin was taken daily thereafter.

Graft surveillance. Endpoints of the study were patency and LS rates, and death. Postoperative assessments included clinical examinations with ABI measurement and duplex scan imaging in all patients at discharge, and duplex scan imaging after 30 days and then at 3-month intervals during the first year, then every 6 months thereafter. Follow-up always included a color duplex investigation of the inflow artery, the whole vein conduit, both anastomoses, and the initial tract of the outflow artery. A duplex ultrasound scan was considered abnormal if the focal peak systolic flow velocity was >200 cm/s, the velocity ratio >2.0, or the global graft flow velocity <45 cm/s. No color flow in the graft was indicative of occlusion. The patency data for patients who died were considered up until the last time their graft had been found patent. For each endpoint, we considered the midpoint in the interval between when the graft had last been found patent and when it was revised or clearly shown occluded.

Data and statistical analyses. The data are presented and analyzed with the standards recommended by the ad hoc committee on reporting standards.[20] Primary patency (PP) was defined as uninterrupted duration of patency of the original graft without any intervention; primary

Table I. Demographics, risk factors, and preoperative ABI measurements

	Study group, n (%)	*Control group, n (%)*	P *value*	*Total, n (%)*
Patients	69	187		256
Procedures	69	187		256
Age (yr), mean ± SD	68 ± 7.83	70 ± 6.44	.039	
range	55-78	59-85		
Men	49 (71)	123 (65.7)	.428	172 (67.2)
Risk factors				
Diabetes mellitus	45 (65.2)	94 (50.2)	.033	139 (54.3)
diet controlled	3 (4.3)	8 (4.2)	1[c]	11 (4.3)
oral agent	6 (8.7)	15 (8.0)	.862	21 (8.2)
insulin-dependent	36 (52.2)	71 (37.9)	.041	107 (41.8)
Creatinine > 2.0 mg/dL	13 (18.8)	45 (24.1)	.372	58 (22.6)
dialysis dependence	4 (5.8)	2 (1.1)	.047[c]	6 (2.3)
Smoking[a]	52 (75.3)	109 (58.2)	.012	161 (62.9)
CAD	43 (62.3)	113 (60.5)	.783	156 (60.9)
Prior MI	24 (34.8)	51 (27.3)	.241	75 (29.3)
Prior PTA stenting/CABG	19 (27.5)	39 (20.1)	.257	58 (22.6)
Prior stroke	9 (13.0)	17 (9.1)	.353	26 (10.1)
Hypertension[b]	46 (66.6)	121 (64.7)	.134	167 (65.2)
Prior inflow procedures	14 (20.3)	47 (25.1)	.420	61 (23.8)
ABI	0.40 ± 0.22	0.43 ± 0.21	.317[d]	
ABI excluding values ≥ 1.2 (medial sclerosis)	0.32 ± 0.18	0.36 ± 0.14	.062[d]	

CAD, Coronary artery disease; *MI,* myocardial infarction; *PTA,* percutaneous transluminal angioplasty; *CABG,* coronary artery bypass grafting; *ABI,* ankle-brachial index.
[a]defined by patient history.
[b]defined as blood pressure treated with medication.
[c]Fisher test.
[d]Student *t* test.

"assisted" patency (PAP) was defined as uninterrupted duration of patency assisted by simple measures (primarily percutaneous transluminal angioplasty [PTA] or patch angioplasty) while the original graft remaining free of thrombosis; and secondary patency (SP) was defined as duration of patency of the original graft that thrombosed but was kept patent by thrombectomy, thrombolytic therapy, PTA, patch graft angioplasty, and any other suitable procedure. LS was defined as preservation of the affected limb with no need for amputation above the metatarsal level.

Continuous data were compared with Student *t* test. Frequencies and categorical data were compared with a χ^2 or Fisher exact test, as appropriate. A Cox proportional hazard analysis was used to identify which factors could influence bypass graft patency and LS. All tests were two-tailed and statistical significance was inferred at a P value < 05. PP, PAP, SP, and LS rates and survival for both groups were assessed by Kaplan-Meier analysis and the Mantel-Cox log-rank test was used to compare survival curves between the groups: results are presented as odds ratios (OR) and 95% confidence intervals (95% CI) with corresponding *P* value.

RESULTS

During the study period, 651 infrapopliteal bypass procedures were performed in 597 patients for CLI at our institution. The distal anastomosis was located at PA level in 214 (32.8%) revascularizations, and the outflow vessel was the terminal PA in 69 cases (69 patients; study group). The distal PA was chosen as the target vessel: (1) because the proximal, mid-PA was occluded or severely diseased, and no other adequate inframalleolar or PB arteries were identified preoperatively (n = 30; 43.5%); (2) because an alternative inframalleolar target vessel was present but severely diseased (n = 9; 13%); (3) because of the length limitations of the available vein (n = 12; 17.4%; or 4) because of the presence of invasive infection or necrosis overlying the DP or PT arteries (n = 18; 26.1%). During the same period, 187 autologous vein bypass grafts were performed to 179 inframalleolar (92 TPAs and 87 DPs) and 8 PB arteries in 187 patients (control group). No group of patients managed conservatively or undergoing primary amputation or primary interventional therapy was considered for comparison. Bypass procedures to arteries proximal to the ankle or involving prosthetic conduits were excluded from the analysis.

Preoperative demographic data, risk factors and ABI measurements for the two groups are shown in Table I. The population was predominantly male, with significantly younger patients in the study group (68 ± 7 years vs 70 ± 6 years, $P = .039$). The PA group had a statistically higher incidence of diabetes mellitus (65.2% vs 50.2%, $P = .033$) and insulin dependence (52.2% vs 37.9%, $P = .041$), dialysis-dependent CKD (5.8% vs 1.1%, $P = .047$), and history of smoking (75.3% vs 58.2%, $P = .012$) than the control group. The degree of preoperative foot ischemia as measured by ABI was comparable between the study and control groups (0.40 ± 0.22 vs 0.43 ± 0.21; $P = .317$) and, although it was worse in the study group after patients with artificially elevated ABIs due to the medial sclerosis

Table II. Indications for surgery, inflow source, type of conduit, runoff scores, and preoperative foot care procedures

	Study group, n (%)	*Control group, n (%)*	P *value*	*Total, n (%)*
Indications for surgery				
Gangrene/nonhealing ulcers	61 (88.4)	163 (87.2)	.790	224 (87.5)
toe	43 (62.3)	121 (64.7)	.724	164 (64.1)
fore-foot	7 (10.1)	17 (9.1)	.797	24 (9.4)
mid-foot	2 (2.9)	7 (3.7)	.545[a]	9 (3.5)
hind-foot	9 (13.1)	18 (9.6)	.430	27 (10.5)
Rest pain	8 (11.6)	24 (12.8)	.790	32 (12.5)
Infection	23 (33.3)	67 (35.8)	.711	90 (35.1)
Inflow artery				
CFA	44 (63.8)	98 (52.4)	.105	142 (55.4)
DFA	3 (4.3)	10 (5.3)	.746[a]	13 (5.1)
Distal SFA/AK Popliteal	13 (18.8)	55 (29.4)	.089	68 (26.6)
BK popliteal/ TPT	9 (13.1)	24 (12.8)	.965	33 (12.9)
Type of conduit				
Homo- or contralateral GSV	62 (89.8)	175 (93.6)	.313	237 (92.6)
Spliced vein (GSV, SSV, arm)	7 (10.2)	12 (6.4)		19 (7.4)
Runoff score				
0	0	69 (36.9)		
1	25 (36.2)	86 (46)		
2	31 (45)	28 (15)		
3	10 (14.5)	4 (2.1)		
4	3 (4.3)	0		
Preoperative foot care procedure				
drainage	18 (26.1)	51 (27.3)	.850	69 (26.9)
debridement	13 (18.8)	56 (29.9)	.076	69 (26.9)

CFA, Common femoral artery; *DFA,* deep femoral artery; *SFA,* superficial femoral artery; *AK,* above the knee; *BK,* below the knee; *TPT,* tibio-peroneal trunk; *GSV,* great saphenous vein; *SSV,* small saphenous vein.
[a]Fisher exact test.

had been ruled out, the difference failed to reach statistical significance (0.32 ± 0.18 vs 0.36 ± 0.14; $P = .062$). There were no statistically significant differences between the groups in terms of gender, CAD, arterial hypertension, history of myocardial infarction or CKD, history of cardiac operations or cerebrovascular events, and previous inflow procedures. Indications for surgery, inflow sources, type of conduit, runoff scores, and preoperative foot care procedures are summarized for both groups in Table II.

Perioperative (30-day) results. None of the patients died in the perioperative period. There were three early graft failures (one in the PA group) prompting three above-knee amputations (Table III). No statistically significant differences emerged between the two groups as concerns the improvement of the postoperative ABI measurement, systemic and local perioperative complications, and perioperative additional foot care procedures (Table III).

Long-term results. Complete follow-up (range, 0.1-10.2 years; mean, 5.8 years) was obtained in 245 (95.7%) patients (66 were in the study group). The PP rates are given in Fig 1: at 1, 5, and 10 years, they were 87%, 70.8%, and 67.4% in the PA group and 88%, 71.9%, and 68.4% in the control group ($P = .886$; OR = 1.038, 95% CI = 0.608-1.777).

The PAP rates are given in Fig 2: at 1, 5, and 10 years, they were 89.7%, 73%, and 69.6% in the PA group and 89.1%, 75.5%, and 71.7% in the control group ($P = .870$; OR = 1.047, 95% CI = 0.594-1.847). All the lesions involved were detected at duplex scan and were intrinsic vein graft defects equally distributed along the length of the graft. Graft revision involved three PTAs (two in the PA group) and four patch angioplasties in the control group.

The SP rates are given in Fig 3: at 1, 5, and 10 years, they were 91%, 75.8%, and 72.2% in the PA group and 90.6%, 76.6%, and 72.8% in the control group ($P = .989$; OR = 0.995, 95% CI = 0.551- 1.798). Overall, SP was achieved in five grafts: three of them (one in the PA group) failed within the first 3 months after surgery, while two (one in the PA group) failed 29 and 18 months, respectively, after surgery due to outflow disease secondary to myointimal proliferation and hyperplasia.

The LS rates are given in Fig 4: at 1, 5, and 10 years, they were 95.5%, 91.9%, and 91.9% in the PA group and 96.1%, 93%, and 93% in the control group ($P = .659$; OR = 1.270, 95% CI = 0.416-3.982). LS was facilitated by additional procedures on the foot. Although the need for minor amputation was statistically more frequent in the PA group (78.2% vs 63.1%, $P = .022$), especially when it concerns partial calcanectomy (8.7% vs 2.1%, $P = .026$), the proportion of wounds completely healed during the follow-up and the mean time to wound healing were comparable in the two groups (Table III). Overall, there were 15 major amputations, 9 below the knee (3 in the PA group) and 6 above the knee (2 in the PA group); only 4 of them (1 in the PA group) were needed to treat chronic neuropathic heel ulcer (n = 2) or progressive ascending gangrene (n = 2) despite a patent bypass graft. Two-thirds

Table III. Perioperative (30-day) results, and rate and timing of wound healing

	Study group, n (%)	*Control group, n (%)*	P *value*	*Total, n (%)*
Death	0	0		0
Major amputation	1 (1.4)	2 (1.1)	1	3 (1.2)
ABI measurements	0.89 ± 0.12	0.94 ± 0.21	.063[b]	
Systemic complications	17 (24.6)	31 (16.5)	.143	48 (18.7)
Nonfatal MI	1 (1.4)	1 (0.5)	.467[a]	2 (0.8)
Heart failure	3 (4.3)	2 (1.1)	.123[a]	5 (1.9)
Pneumonia	4 (5.8)	6 (3.2)	.466[a]	10 (3.9)
Arrhythmia	7 (10.1)	20 (10.7)	.899	27 (10.5)
Renal failure	2 (2.9)	2 (1.1)	.294[a]	4 (1.5)
Minor complications	7 (10.1)	24 (12.8)	.558	31 (12.1)
Hematoma	3 (4.3)	14 (7.5)	.572[a]	17 (6.6)
Lymphocele	2 (2.9)	6 (3.2)	.630[a]	8 (3.1)
Wound dehiscence	2 (2.9)	4 (2.1)	.662[a]	6 (2.3)
Additional local procedures	16 (23.2)	47 (2.1)	.748	63 (24.6)
Drainage	10 (14.5)	29 (15.5)	.841	39 (15.2)
Debridement	6 (8.7)	18 (9.6)	.821	24 (9.3)
Minor amputation	54 (78.2)	118 (63.1)	.022	172 (67.1)
Toe(s), ray(s)	41 (59.4)	98 (52.4)	.318	139 (54.3)
Transmetatarsal	7 (10.1)	16 (8.5)	.693	23 (8.9)
Partial calcanectomy	6 (8.7)	4 (2.1)	.026[a]	10 (3.9)
Wounds healed	43 (70.4)	147 (80.3)	.109	190 (74.2)
Time to wound healing, wk	23 ± 19.9	20 ± 8.9	.107	

MI, Myocardial infarction.
[a]Fisher exact test.
[b]Student t test.

of the amputations were performed within the first postoperative year.

All potentially prognostic patient variables (including age, gender, diabetes mellitus, CKD or dependence on dialysis, smoking, CAD, prior myocardial infarction or cardiac interventions, arterial hypertension, prior stroke or inflow procedures and inflow source, and run-off scores) were submitted to univariate or multivariate Cox proportional hazards analysis as possible predictors of bypass failure: none of these variables emerged as a significant predictor either in the series as a whole or in either group.

Overall, there were 55 late deaths, 16 of them in the PA group. The survival rates are given in Fig 5: at 1, 5, and 10 years, they were 100%, 71.4%, and 59.9% in the PA group and 98.8%, 67.5%, and 58.1% in the control group (P = .584; OR = 0.852, 95% CI = 0.480-1.512).

DISCUSSION

Although revascularization to infrapopliteal arteries has proven to be a safe, effective, and durable procedure for LS in the critically ischemic foot,[1-10] the terminal PA has rarely been considered as a suitable outflow option[23] because the PA lacks continuity with the pedal arteries, and exposing the distal third of the vessel can prove troublesome.

After arterial reconstruction using the terminal PA, our patency and LS rates were comparable with those achieved during the same period using the other inframalleolar arteries, though they were slightly lower for the PA group in all analyses at 5 and 10 years. These findings are in contrast with the higher 4-year LS rate of 160 tibial and pedal bypass grafts compared with 34 PA bypass procedures (67% vs 55%, P = .017) reported by Elliott et al[16] who identified a PA length < 10 cm as one of the four anatomical features associated with failure after PA bypass grafting. In a later study, the same authors compared the results of PA and inframalleolar bypasses for ischemic tissue loss (including, however, only 18 PA bypasses performed for tissue loss) and concluded that PA revascularization afforded a 3-year LS rate statistically lower to that of the inframalleolar bypasses (33% vs 63%; P = .048) when the indication for surgery was tissue necrosis.[17] On the other hand, our patency and LS rates correlate well with the only previously-published study dealing with the terminal PA being used in primary or secondary distal revascularizations for CLI because a more proximal outflow vessel was unavailable:[23] in a series of 159 revascularizations performed in 143 patients during a 14-year period, Darling et al[23] reported 1- and 5-year SP rates of 86% and 75%, respectively, with a 5-year LS rate of 87%, demonstrating that these reconstruction procedures achieved much the same hemodynamic results as PT or DP, and PB bypass grafts. Revascularizations to the distal third of the PA were also found as reliable in effecting LS as the proximal two thirds of the PA or other perimalleolar arteries in the same investigators' hands,[1,5,8,10] and their results were comparable with those obtained by many authors advocating the use of PA bypass procedures for LS, though none of them specifically focused on the terminal PA.[2-4,6,7,9]

In our study, the mean time to wound healing and the proportion of wounds completely healed during the follow-up were similar after distal PA or inframalleolar and PBs bypasses, despite a significantly higher incidence of

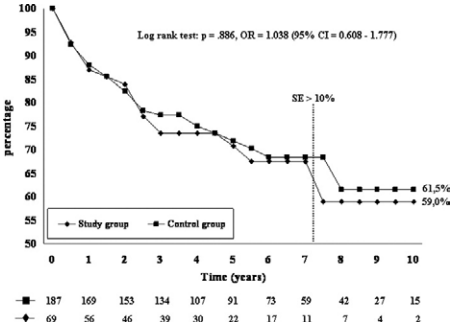

Fig 1. Kaplan-Meier life table analysis of primary patency rates in the study (*diamonds*) and control (*squares*) groups. Percentages on the right represent the primary patency rates at 10 years for the groups. Standard errors exceed 10% after 7.2 years in both groups. Raw number of the limbs at risk analyzed for each interval time is shown for each group.

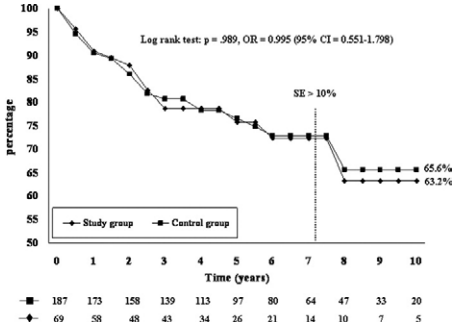

Fig 3. Kaplan-Meier life table analysis of secondary patency rates in the study (*diamonds*) and control (*squares*) groups. Percentages on the right represent the secondary patency rates at 10 years for the groups. Standard errors exceed 10% after 7.2 years in both groups. Raw number of the limbs at risk analyzed for each interval time is shown for each group.

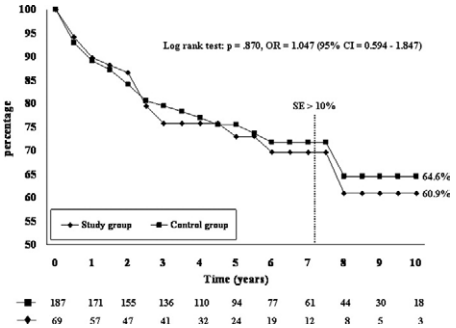

Fig 2. Kaplan-Meier life table analysis of primary "assisted" patency rates in the study (*diamonds*) and control (*squares*) groups. Percentages on the right represent the primary "assisted" patency rates at 10 years for the groups. Standard errors exceed 10% after 7.2 years in both groups. Raw number of the limbs at risk analyzed for each interval time is shown for each group.

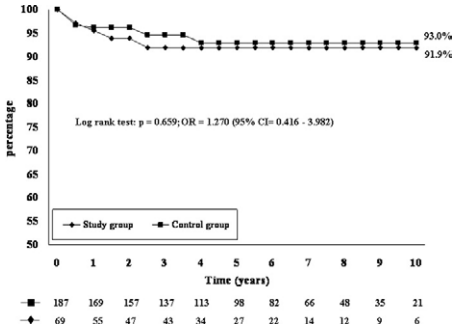

Fig 4. Kaplan-Meier life table analysis of limb salvage rates in the study (*diamonds*) and control (*squares*) groups. Percentages on the right represent the limb salvage rates at 10 years for the groups. The range of standard errors for the study group is 0% to 3.8%, whereas the range of standard errors for the control group is 0% to 3.1%. Raw number of the limbs at risk analyzed for each interval time is shown for each group.

additional minor amputations (especially partial calcanectomy) in the PA group. We, consequently, confute the assumption that the lack of any direct connection between PA and the pedal vessels, or the reduced collateral bed when the terminal PA is involved, reduces the chances of healing open foot wounds in ischemic, often infected, or contaminated fields.[1,7,16] In a series of 62 bypasses to the PA, Shortell et al[2] found no correlation between patency and direct communication with the pedal vessels, and Synn et al[3] and Plecha et al[4] were unable to demonstrate any correlation between patency and preoperative angiographic scores. Moreover, in a study on the clinical and hemodynamic results of bypasses to isolated tibial artery segments, Belkin et al[24] found hemodynamic graft failures no more common with distal PA than with other distal reconstructions.

Particular features of our study were that: (1) all but four terminal PAs were exposed through a lateral approach; (2) the surgical technique involved standard vein patching and subsequent implantation of the vein graft in the patch; and (3) all patients received adequate anticoagulation therapy.

Unlike the majority of authors who expose the PA through a medial route,[1,4,5,8,10,23] like Dardik et al[25] and Kahn et al,[26] we found that the lateral approach to the PA provides excellent exposure of the PA distal tract, and, in our opinion, it is quicker and easier than the medial approach.

To our knowledge, no other authors (apart from Linton and Wilde[27]) have used venous patching at distal anastomotic level when the conduit was the vein. To overcome technical difficulties encountered in anastomosing small-caliber, thin-walled vein conduits to thick-walled diseased arteries, and to contain the compliance mismatch between the target artery and the vein conduit, since 1986 our technique has involved standard vein patching and then the implantation of the conduit in the patch in all infrapopliteal distal anastomoses.[28]

Complementary therapy with warfarin is reportedly important in improving the patency rates of prosthetic graft

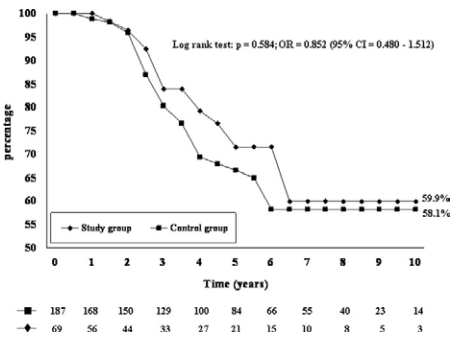

Fig 5. Kaplan-Meier life table analysis of survival rates in the study (*diamonds*) and control (*squares*) groups. Percentages on the right represent the survival rates at 10 years for the groups. The range of standard errors for the study group is 0% to 9.5%, whereas the range of standard errors for the control group is 0% to 6.1%. Raw number of the patients at risk analyzed for each interval time is shown for each group.

in patients needing arterial reconstruction to infrapopliteal vessels, whereas the benefit of anticoagulation therapy in patients with venous distal revascularizations appears controversial.[29-31] Because we used both vein patch angioplasty and anticoagulation therapy in both our groups, we cannot say how these factors, alone or in combination, may have influenced our patency rates.

The major shortcomings of this study are its retrospective nature (despite a prospective data collection) and the inadequacy of the sample size for the purpose of detecting differences between groups with adequate statistical power. A further limitation concerns the exclusion of patients with ischemic soft tissue breakdown between the calcaneus and metatarsal heads. In our experience, however, many patients with extensive soft tissue loss in the plantar region undergoing a distal revascularization - whatever the outflow vessel chosen or the additional techniques used at the distal anastomotic site (vein patch or cuff, arteriovenous fistula) - underwent late major amputation (usually despite a patent graft) due to recurrent deep infections delaying healing for months, or because minor postoperative amputations more proximal than at metatarsal level made walking awkward or difficult. Had we included these patients too, our results, in terms of LS, would probably have been negatively affected by clinical events unrelated to the outflow site.

In conclusion, this study offers a useful comparison of patency, LS, and wound healing times and rates after revascularization to the distal PA and other inframalleolar or PB arteries, providing evidence that the choice of outflow vessel does not influence the outcome of the arterial reconstruction. The successful wound healing in the PA group goes to show that revascularization to the terminal PA affords adequate tissue perfusion and that the lack of any direct communication between the PA and the major pedal vessels is no reason to reject the PA as the last-choice outflow vessel for distal revascularization.

AUTHOR CONTRIBUTIONS

Conception and design: EB, GDG, BM
Analysis and interpretation: GDG, BM
Data collection: FM
Writing the article: EB, GDG, BM
Critical revision of the article: EB, GDG, BM
Final approval of the article: EB, GDG, MG, FM, BM
Statistical analysis: MG
Obtained funding: Not applicable
Overall responsibility: EB

REFERENCES

1. Karmody AM, Leather RP, Shah DM, Corson JD, Naraynsingh V. Peroneal artery bypass: a reappraisal of its value in limb salvage. J Vasc Surg 1984;1:809-16.
2. Shortell CK, Ouriel K, DeWeese JA, Green RM. Peroneal artery bypass: a multifactorial analysis. Ann Vasc Surg 1992;6:15-9.
3. Synn AY, Hoballah JJ, Sharp WJ, Kresowik TF, Corson JD. Are there angiographic predictors of success for vein bypass to the peroneal artery? Am J Surg 1992;164:276-80.
4. Plecha EJ, Seabrock GR, Bandyk DF, Towne JB. Determinants of successful peroneal artery bypass. J Vasc Surg 1993;17:97-106.
5. Shah DM, Paty PSK, Leather RP, Chang BB, Darling RC 3rd, Feustel PJ. Optimal outcome after tibial arterial bypass. Surg Gynecol Obstet 1993;177:283-7.
6. Schneider JR, Walsh DB, McDaniel MD, Zwolak RM, Besso SR, Cronenwett JL. Pedal bypass versus tibial bypass with autogenous vein. A comparison of outcome and hemodynamic results. J Vasc Surg 1993;17:1029-40.
7. Bergamini TM, George SM, Massey HT, Henke PK, Klamer TW, Lambert GE, et al. Pedal or peroneal bypass: which is better when both are patent? J Vasc Surg 1994;20:347-56.
8. Darling RC 3rd, Chang BB, Paty PSK, Lloyd WE, Leather RP, Shah DM. Choice of peroneal or dorsalis pedis artery bypass for limb salvage. Am J Surg 1995;170:109-12.
9. Abou-Zamzam AM, Moneta GL, Lee RW, Nehler MR, Taylor LM, Porter JM. Peroneal bypass is equivalent to inframalleolar bypass for ischemic pedal gangrene. Arch Surg 1996;131:894-9.
10. Paty PSK, Darling RC 3rd, Kreienberg PB, Lloyd WE, Chang BB, Papanicolaou G, et al. Determinants of peroneal artery bypass failure. Vasc Surg 1998;32:603-8.
11. Reichle FA, Tyson RR. Femoroperoneal bypass: evaluation of potential for revascularization of the severely ischemic lower extremity. Ann Surg 1972;181:182-5.
12. Sumner DS, Strandness DE. Hemodynamic studies before and after extended bypass grafts to the tibial and peroneal arteries. Surgery 1979;86:442-52.
13. Szilagyi DE, Hageman JH, Smith RF, Elliot JP, Brown F, Dietz P. Autogenous vein grafting in femoropopliteal arteriosclerosis: the limits of its effectiveness. Surgery 1979;86:836-51.
14. Graham JW, Hanel KC. Vein graft to the peroneal artery. Surgery 1981;89:264-7.
15. Dible JH. The pathology of limb ischemia. Edinburgh: Oliver & Boyd;1966 p. 39-71.
16. Elliott BM, Robison JG, Brothers TE, Cross MA. Limitations of peroneal artery bypass grafting for limb salvage. J Vasc Surg 1993;18:881-8.
17. Robison JG, Cross MA, Brothers TE, Elliott BM. Do results justify an aggressive strategy targeting the pedal arteries for limb salvage? J Surg Res 1995;59:450-4.
18. Connors JP, Walsh DB, Nelson PR, Powell RJ, Fillinger MF, Zwolak RM, et al. Pedal branch artery bypass: a viable limb salvage option. J Vasc Surg 2000;32:1071-9.
19. Anderson CB, Stevens SL, Allen BT, Sicard GA. In situ saphenous vein for lower extremity revascularizations. Surgery 1992;112:6-10.
20. Rutherford RB, Baker JD, Ernst C, Johnston KW, Porter JM, Ahn S, et al. Recommended standards for reports dealing with lower extremity ischemia: revised version. J Vasc Surg 1997;26:517-38.

21. Ballotta E, Renon L, De Rossi A, Barbon B, Terranova O, Da Giau G. Prospective randomized study on reversed saphenous vein infrapopliteal bypass to treat limb-threatening ischemia: common femoral artery versus superficial femoral or popliteal and tibial arteries as inflow. J Vasc Surg 2004;40:732-40.
22. Ballotta E, Renon L, Toffano M, Piccoli A, Da Giau G. Patency and limb salvage rates after distal revascularization to unclampable calcified outflow arteries. J Vasc Surg 2004;39:539-46.
23. Darling RC 3rd, Shah DM, Chang BB, Lloyd WE, Paty PSK, Leather RP. Arterial reconstruction for limb salvage: is the terminal peroneal artery a disadvantaged outflow tract? Surgery 1995;118:763-7.
24. Belkin M, Welch HJ, Mackey WC, O'Donnell TF. Clinical and hemodynamic results of bypass to isolated tibial artery segments for ischemic ulceration of the foot. Am J Surg 1992;164:281-5.
25. Dardik H, Dardik I, Veith FJ. Exposure of the tibial peroneal artery by a single lateral approach. Surgery 1974;75:377-83.
26. Kahn MB, Profeta B, Hume E, Leichter R, Carabasi A, DiMuzio PJ. Tibia fracture after fibula resection for distal peroneal bypass. J Vasc Surg 2001;34:979-82.
27. Linton RR, Wilde WL. Modifications in the technique for femoropopliteal saphenous vein bypass autografts. Surgery 1970;67:234-48.
28. Ballotta E, Alvino S, Franceschi L, Grego F, Deriu GP. An effective surgical technique for limb salvage in femoro-distal bypass. Vasc Surg 1988;22:154-9.
29. Sarac TP, Huber TS, Back MR, Ozaki CK, Carlton LM, Flynn TC, et al. Warfarin improves the outcome of infrainguinal vein bypass grafting at high risk for failure. J Vasc Surg 1998;28:446-57.
30. Dutch Bypass Oral Anticoagulants or Aspirin (BOA) Study Group. Efficacy of oral anticoagulants compared with aspirin after infrainguinal bypass surgery: a randomized trial. Lancet 2000;355:346-51.
31. Johnson WC, Williford WO, and members of the Department of Veterans Affairs Cooperative Study # 362. Benefits, morbidity, and mortality associated with long-term administration of oral anticoagulant therapy to patients with peripheral arterial bypass procedures: a prospective randomized study. J Vasc Surg 2002;35:413-21.

Submitted Nov 20, 2007; accepted Jan 1, 2008.